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urally show a relatively dark central area, but the projection principle may not be the only one involved.

If this nebula is in process of development into a solar system, the indications are for a system having certain resemblances to our solar system. Our four outer planets have a combined mass 225 times as great as that of the four inner planets. Similarly in N. G. C. 7009, there is apparently a paucity of material to form planets near the nucleus and an abundance of material for planets at greater distances from the nucleus.

In the course of our determinations of nebular velocities in the past three years we have noted a relatively large number of ring forms among the planetaries, and we have observed no extremely-elongated or highly-elliptic gaseous nebulae, and no such forms of gaseous nebulae as would result from thin rings seen edge-wise. According to the probabilities of the case, if the apparent ring nebulae are really of ring form in space, we should have expected to see a number of very elongated elliptic rings and a certain number of relatively long and narrow nebulae. We are accordingly led to question whether the ring nebulae are true rings or whether they are in reality ellipsoidal shells of nebulosity, which appear to be rings wholly or in part by virtue of their projection upon the plane of sight.

Students of cometary orbits in the past five years have apparently established the Kantian view, that comets are bona fide members of our solar system. The observed fact that comets approach the Sun without marked preference for any direction of origin has seemed to be difficult to account for on the more prominent hypotheses of the evolution of the solar system. If the planetary nebula N. G. C. 7009 and other planetaries which involve the ring form have in reality three principal dimensions and are developing into solar systems, the more or less uniform distribution of cometary matter in space of three dimensions does not seem to call for surprise.

A SHORT PERIOD CEPHEID WITH VARIABLE SPECTRUM

By Harlow Shapley

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The most suggestive indication that the stars actually develop from one physical condition represented by a definite spectral type into other closely allied conditions, if it is not in fact the only direct observational evidence of stellar evolution, is afforded by the spectra of certain short period variable stars. From one star to the next in all regions of the sky we observe continuous gradations of many constant characters, such as spectrum, intrinsic luminosity, and motion. That a star begins, passes through and ends its light-emitting career without change of spectral type is considered impossible. The universal and presumably justifiable assumption is that a given spectrum has developed by imperceptible degrees from an earlier type, and will, given time enough, develop into a later one—that every star, in the course of its life history as a luminous object, passes through many if not most of the principal types and sub-types of the spectral series. This is indeed more than an ordinary assumption; it is a scientific creed. It is now generally accepted by astronomers as an inevitable fact, so nearly axiomatic that its demonstration is no more essential than the proof of the fact of organic evolution. The essential studies concern rather the methods of stellar evolution and its numerous details.

That stellar evolution, as reflected in progressive changes of spectral type, has not been witnessed (the phenomena of novae are nebular rather than stellar) is, of course, no cause to doubt the basic assumption. Observations necessarily have been superficial, and time has been short. It is of interest, therefore, and probably of importance as a proof of stellar evolution to have observed a remarkable change in a star, not only of its light, as in the ordinary variable star, nor merely of its velocity, as in the ordinary double star, but of its very physical make-up. And it is also of importance to know that, when the physical state of a star changes and its intrinsic brightness and surface temperature are affected, the spectrum varies (from one recognizable type to another through known intermediate stages) in exactly the same way as we presume the spectra of all stars have changed or eventually will change. It should be noted, however, that differences in spectra for the most part simply represent dissimilar conditions in the relatively thin atmospheric layer that is the source of the absorption lines; indirectly the deeper structure, even to the center of the star, may be and probably is involved.

In the case under discussion in the present note the variation of spectrum is oscillatory in a period of a few hours, and does not represent, therefore, a secular, irreversible variation of spectral type. It does represent, however, an enormous change in the physical condition at the stellar surface, and exhibits the almost incredible feat of accomplishing in less than two hours time a change of spectrum that for the ordinary development of the ordinary star has been supposed to occupy unknown thousands or millions of years.

The variability of the light of the seventh magnitude star RR Lyrae, the brightest of the cluster-type sub-class of the Cepheid variables, was discovered at Harvard seventeen years ago by the unique method of setting a special automatic photographic telescope to follow the star throughout the night and make a continuous and permanent record of its light. Due to the brightness of the variable and its importance in connection with the study of stellar variation, it has received widespread attention. The light variations have been observed at Harvard, Princeton, the Lick Observatory, the University of Missouri, and at observatories in Italy, Germany, Sweden, and Ireland. Special measures of its position have been made in Finland and in Germany, and observations of the spectrum at Harvard, Lick, and Mount Wilson.

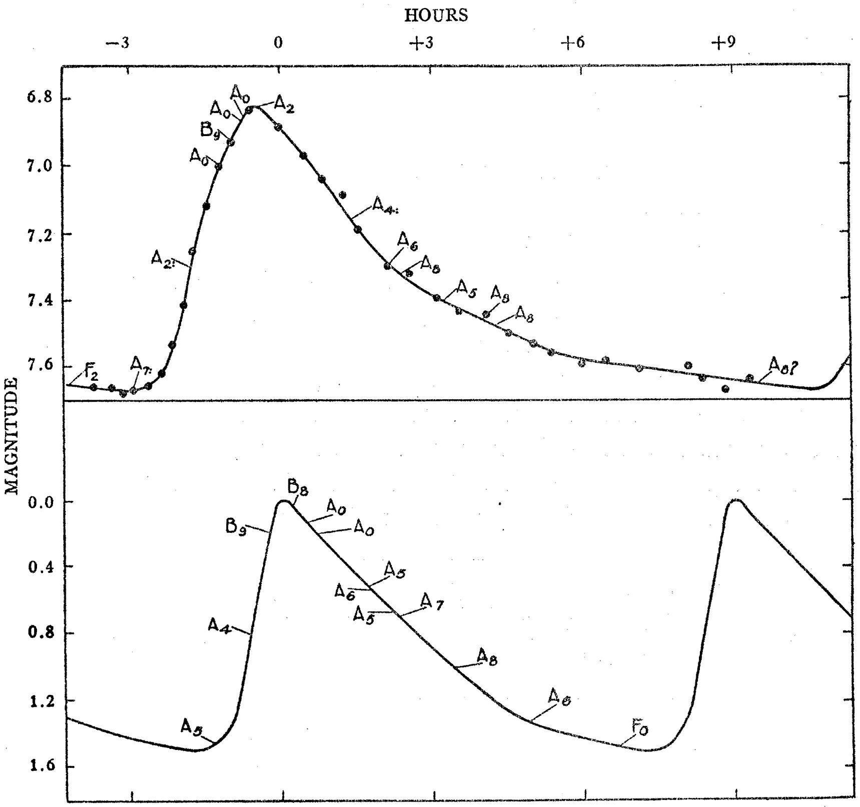

FIG. 1. TOP: MEAN VISUAL LIGHT-CURVE OF RR LYRAE (OBSERVATIONS BY WENDELL) AND VARIATION OF SPECTRUM (SHAPLEY).
BOTTOM: PHOTOGRAPHIC LIGHT-CURVE OF RS BOÖTIS (SEARES AND SHAPLEY) AND VARIATION OF SPECTRUM (PEASE).

Kiess at the Lick Observatory found the star to be a radial-velocity variable—a spectroscopic binary of the peculiar Cepheid type. This linked together the cluster-type and the similar longer-period Cepheid variables, all of which show periodic shifts of the spectral lines, permitting, on the Doppler principle, of interpretation as the result of orbital motion in abnormal but improbable double-star systems. The recent work on the spectrum at Mount Wilson with a 10-inch photographic triplet and an objective prism shows that the spectrum varies between classes A and F in the same period as the variation of light and radial velocity.

The star is, then, a periodic variable in at least three different senses. Every thirteen and a half hours, due to some cause as yet not fully understood, the light increases rapidly, more than doubling its intensity in less than two hours. During the same interval the apparent velocity of the star toward the earth increases from 47 to 91 kilometers a second, and the spectrum changes from type F to type A.

This last variation is probably the most remarkable of all, for it implies, on the basis of our present knowledge of stellar radiation, a change in the temperature at the radiating surface of some three thousand degrees centigrade. Presumably the mean color of the light of RR Lyrae changes perceptibly during these cataclysmic two hours, but the evidence on that point is not yet conclusive.

After the maximum of velocity, of light, and of spectrum have been reached, a reaction sets in, sharply at first, then more gradually, all factors decreasing for nearly half a day. The average time between outbursts is known to a fraction of a second, and the hour of a maximum a century from now could be predicted with considerable certainty. Doubtless a common cause underlies all these variations, and their proper interpretation and correlation will constitute the solution of Cepheid variation.

Though variation of spectral type is suspected in the case of a few other cluster-type variables, and in fact, on the basis of the present results, may be suspected with just cause of all short period Cepheids, the observations have definitely proved the spectrum variable for only two stars. For both of these the spectra have been studied at Mount Wilson, the data for RS Boötis being derived from spectrograms made by Pease at the principal focus of the 60-inch reflector. The results for the two variables are shown graphically in the accompanying figure, where ordinates designate brightness in magnitudes and abscissae give time in hours. The light curve of RS Boötis, along which are plotted the determinations of the spectrum class for the corresponding phases of the light variation, is derived from unpublished photographic observations by Mr. Seares and the writer. The light curve of RR Lyrae is derived from observations made at Harvard.

Although the mean period of RR Lyrae is remarkably constant, conspicuous transitory irregularities are present both in the period and in the form of the light curve, much resembling those of the cluster-type variable XX Cygni previously discussed in these PROCEEDINGS. In particular, there is a slow but definite variation in the length of the period which seems to complete its cycle in about sixteen years; and an oscillation in the time of the rise to maximum light which at times appears to have a uniform period of about forty days, and at other times to be erratic in both period and amplitude. The formula:

$$\text{Max.} = 2414856.451 + 0^{d}.566831E - 0^{d}.024 \sin (0^\circ.0340E - 104^\circ.5)$$
$$+ [0^{d}.004 + 0^{d}.013 \cos \frac{2\pi}{70} (E - 45)]$$

in which E represents the number of periods, predicts the individual maxima with high accuracy for the first seven of eight hundred periods after the initial epoch, and by dropping the short period harmonic it gives the mean maxima accurately for at least fifteen years from the initial date. The complete discussion of these features, based on all the available series of light measures and on the recent observations of the spectrum, will be published as a *Contribution from the Mount Wilson Solar Observatory.*

THE SPECTRUM OF δ CEPHEI

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About 130 years ago Goodricke discovered the periodic fluctuations in the light of the naked-eye star δ Cephei—the eighth variable known to astronomers. None of those previously recorded exhibited the type of light variation peculiar to this fourth magnitude star, but of the four or five thousand variables found since that time more than half show the same character of light fluctuations. The class has, accordingly, received the appropriate designation of Cepheid variables. A century after the discovery of the light variations, δ Cephei was also found to vary in radial velocity—the sixth spectroscopic variable to be placed on record. Again the variation differed from that of other stars. The period of the oscillation of the spectral lines is identical with that of the light variation, but the orbital elements, derived on the hypothesis that the star is a binary, permit no satisfactory explanation of the light variations. When other velocity-variables of this character were found